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WO 92/22882 A1 US 5221924 A US 4155252 A
G.J.Taylor, "Full Scale Measurements in Wind Turbine Arrays" ; European Community Wind Energy cont. Conference, proceedings pub. 1990, H.S.Stephens, Bedford pp. 155-158, see esp. p.156 Boundary-Layer Meteorology, vol.19, no.2, September 1980, Netherlands, H.W.Tennissen, cont. "Structure of Mean Winds and Turbulence in the Planetary Boundary over Rural Terrain" cont. pp.187-221, see esp. pp. 193-4

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INT CL[5] G01P 5/00 13/00
Online databases: WPI, INSPEC

(54) **A system and method for monitoring areal wind characteristics and turbulence caused by wind turbines**

(57) A system for investigating the variation of one or more wind characteristics over a given area comprises a plurality of wind characteristic measuring means 1 each of which outputs a data signal which is indicative of the value of said wind characteristic, the outputs of all the measuring means 1 deployed in the area being relayed to a central receiving unit 5 which may include means 6 for recording the relayed data or may additionally provide means (7, 9) for providing a real-time display of said data. Preferably, each wind characteristic measuring means comprises a balloon or kite-like device tethered to one of a plurality of anchor points distributed around the area (Figs. 2, 3). The system may be used to optimize the siting of wind turbines.

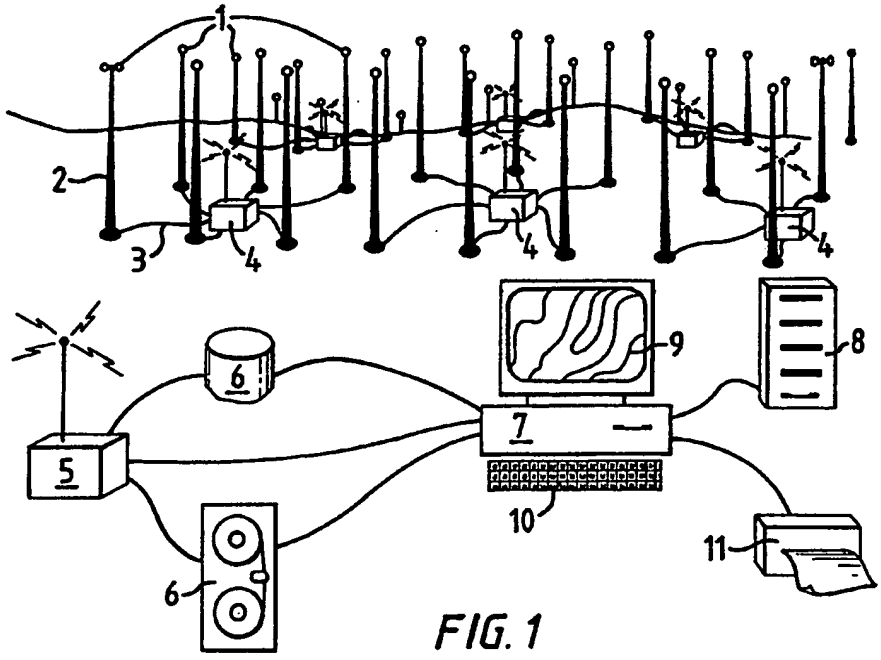

FIG. 1

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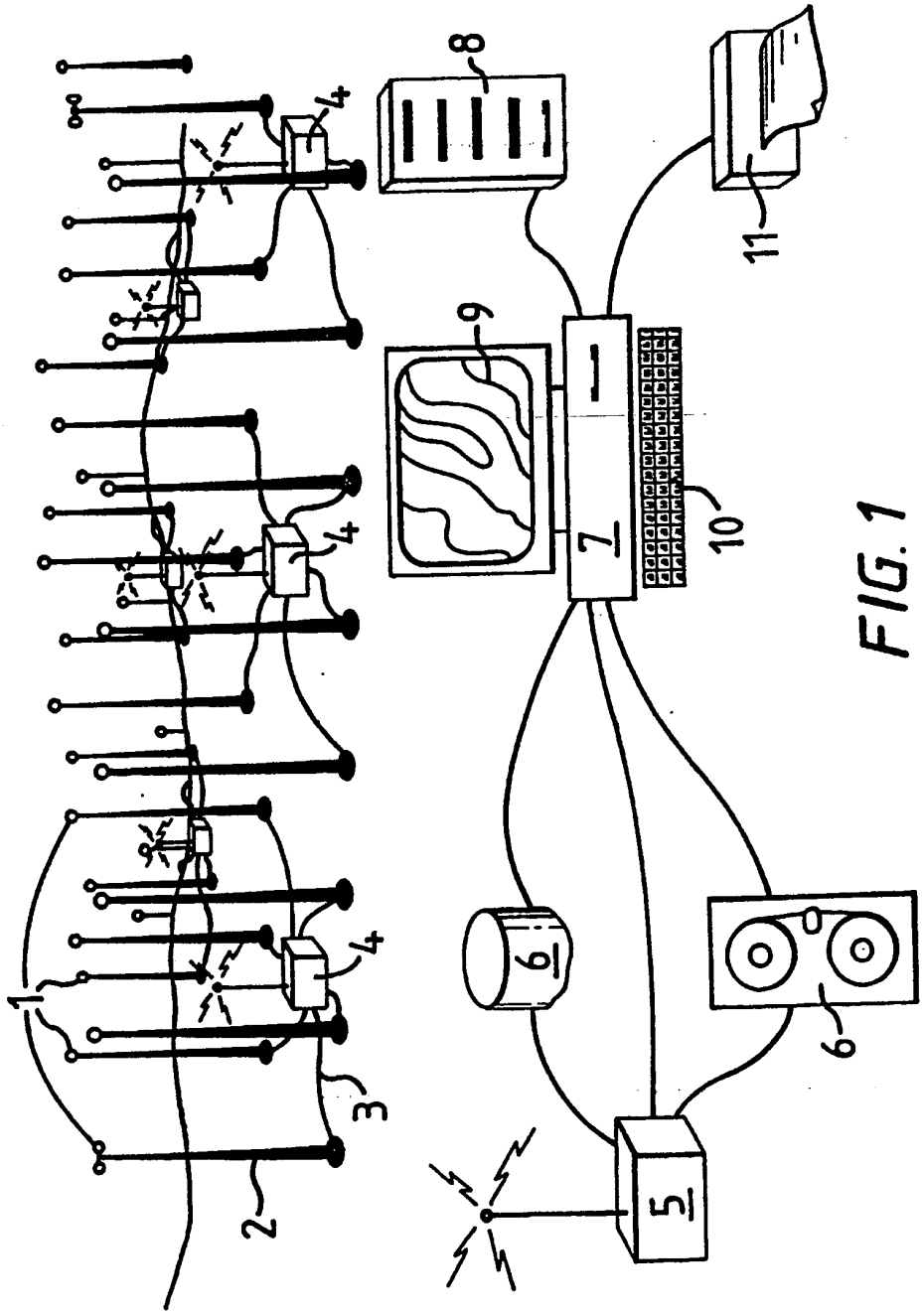

FIG. 1

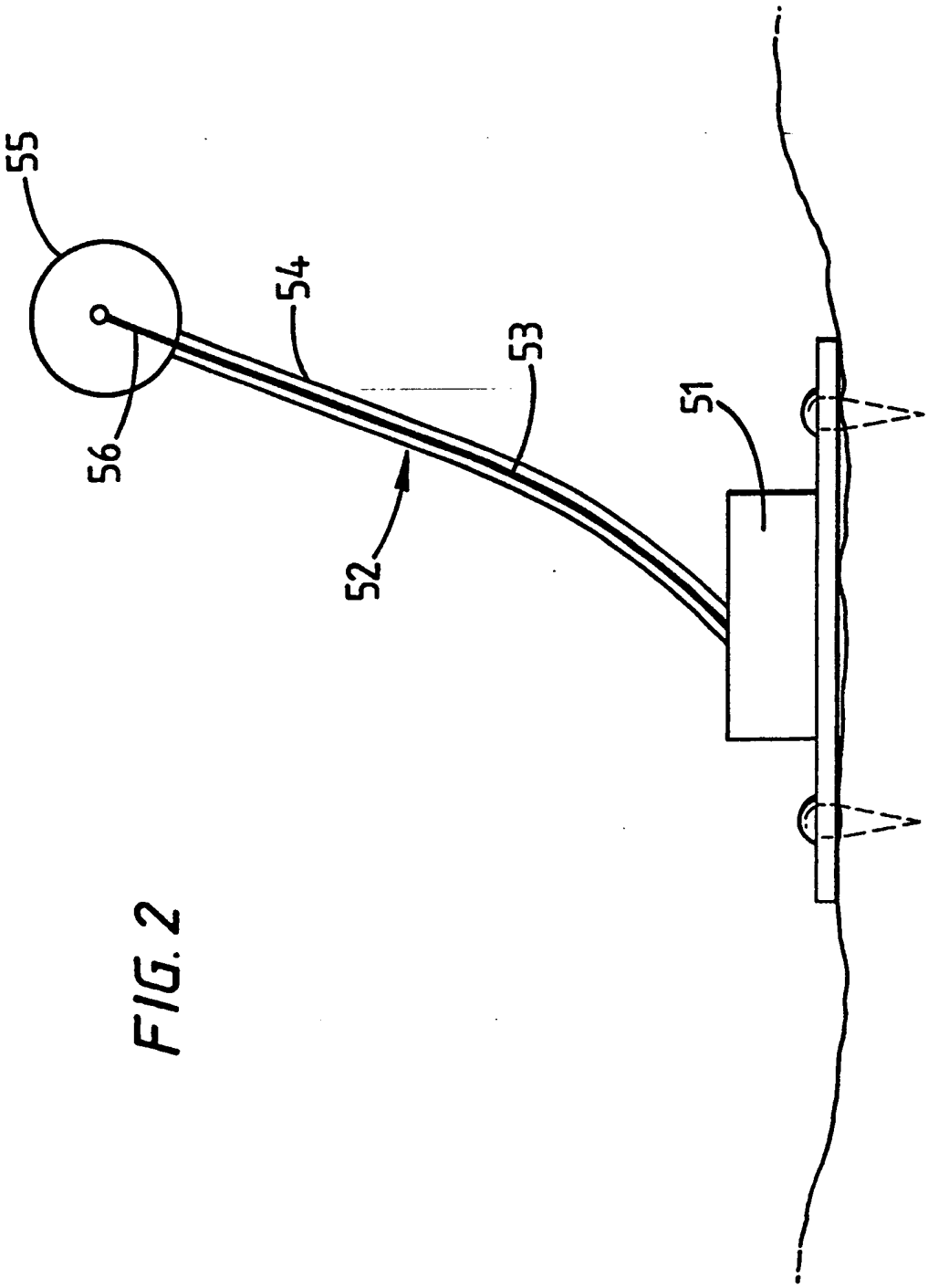

FIG. 2

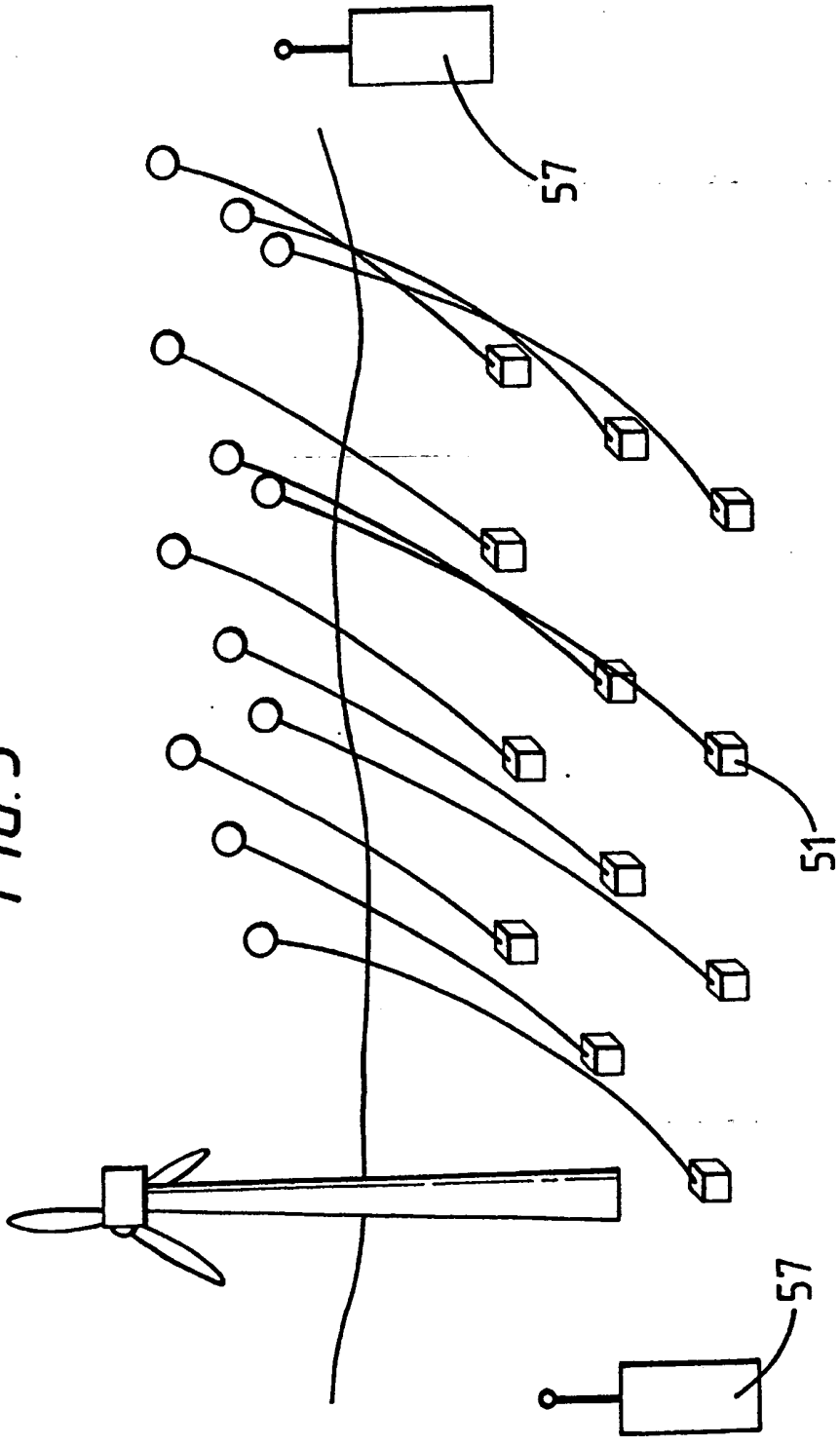

FIG. 3

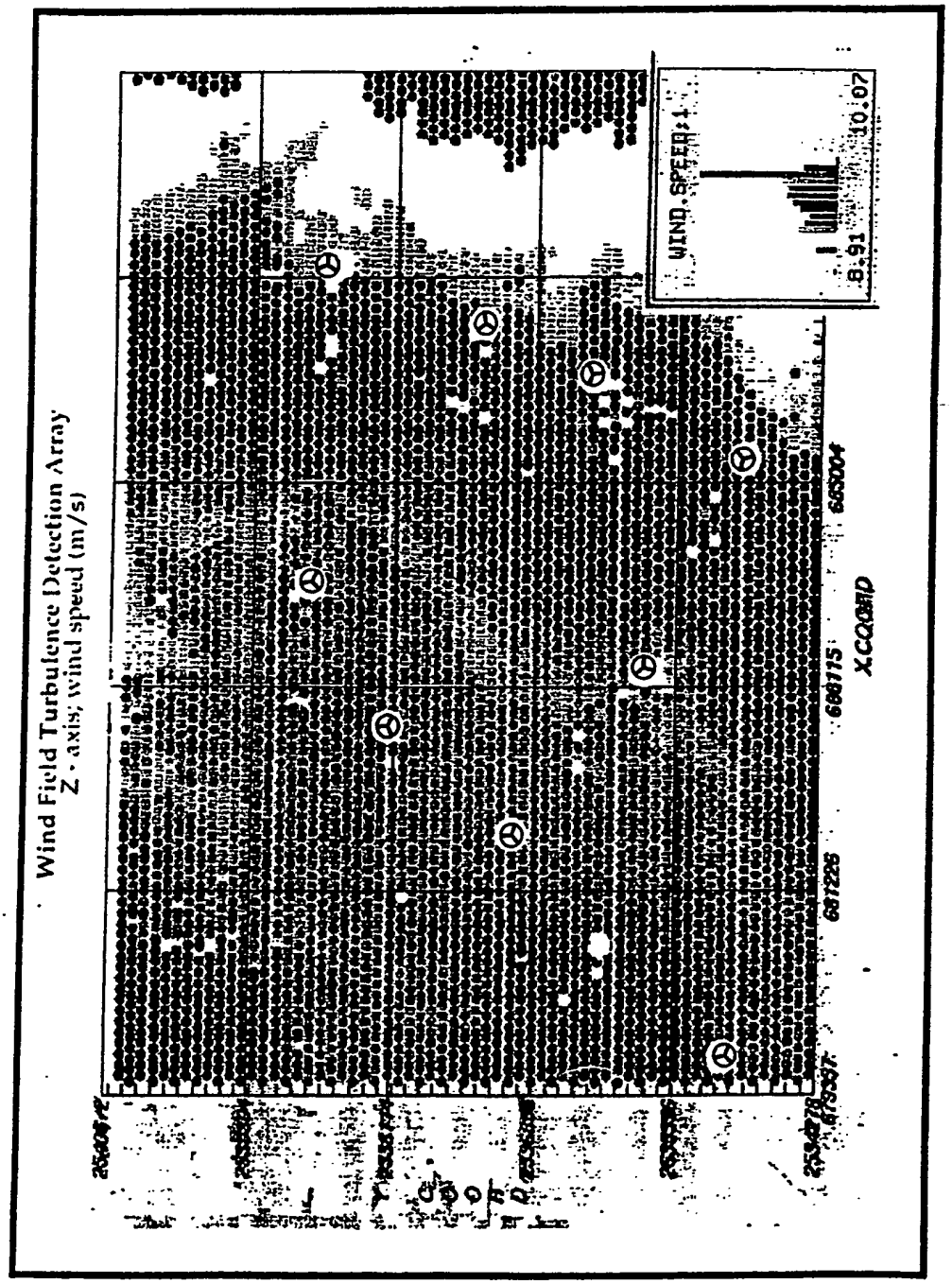
Wind Field Turbulence Detection Array
Z - axis; wind speed (m/s)
WIND SPEED: 1
8.91
10.07
XCOORD
680715
685004
681226

Figure 4

A SYSTEM AND METHOD FOR MONITORING AREAL WIND CHARACTERISTIC AND TURBULENCE CAUSED BY WIND TURBINES

The invention relates to a method and apparatus for monitoring wind characteristics, such as speed, direction and pressure over an area of land, such that data may be collected at frequent and regular intervals with respect to easting, northing elevation and time.

The invention is primarily aimed at, but not limited to providing services for manufacturers, operators and investigators in wind plant, to monitor existing wind farm sites. The invention may allow the modelling of wind flow and equipment turbulence.

The siting of wind energy conversion plant has a direct impact on its operating efficiency and profitability. However, current practice in the industry for siting, often relies upon intuitive judgements based upon relatively sparse wind speed measurements and extrapolation along topographical features such as hill crests, valleys and the like. Trial and error methods based on actual performance are also used.

More dense ground coverage by conventional anemometers and the like is often considered too expensive and impractial for site evaluation. Current practice at established wind sites may limit the locations of anemometers to the wind plant sites only.

A further problem with wind farms is the effect that the wind plant has on the wind field itself. The extraction of wind energy, coupled with the turbulence caused by supporting towers, nacelles etc., changes the actual wind field characteristics relative to that estimated prior to the existence of the plant.

It is an object of the present invention to alleviate some or all of the above-mentioned problems so that siting of wind energy conversion plant can be optimised for any given topography, wind regime and wind energy conversion equipment.

This is to be facilitated by two specific embodiments of the invention.

Firstly, the invention may be deployed over an area of land, such that a model can be built to show wind flow over a given area of land for a number of wind speeds and directions. Interpolation and extrapolation can be used to model all eventualities.

Secondly, the invention can be deployed around a specific piece of wind energy conversion equipment. The purpose of this is to determine the exact shape of the effective turbulence zone emanating from the equipment for all wind speeds. This will provide certifiable data, specific to any piece of equipment.

The invention permits very accurate imaging of what are termed "wind pressure waves". These waves can be imagined when thought of as wind waves blowing

across a wheat field. These waves are important to wind farm operators as they are the manifestation of the wind irregularity, that reduces the quality of electrical power sold by wind farms. The form of these "wind waves" has a very strong linkage to the ground topography, wind direction and speed. Consequently they are very hard to predict and model. The present invention enables measurement of these wind waves directly and therefore allows appropriate siting of plant so as to minimse effects of machine induced turbulence, thereby improving the overall efficiency of the wind farm.

The invention will permit the detection of desirable wind energy "hot spots" and unwanted turbulence zones or areas of low wind speed.

Also the invention provides the means for recording a large body of wind characteristic data, thereby allowing large scale academic and scientific research to be carried out using the recorded data.

The present invention provides a data acquisition method, digital electronic data recording and storage means, high speed data processing and computer aided visualisation means.

According to one aspect of the present invention there is provided a method of monitoring wind characteristics over an area of land, comprising the steps of:

locating a wind characteristic measuring means at each of a number of sites, so that said wind characteristic measuring means are arranged into a

spatial array over said area; each wind characteristic measuring means being adapted to output a data signal which is indicative of the value of one or more wind characteristics,

passing said data signals from each wind characteristic measuring means to a data receiving means; and

processing the received data signals to provide data representing the value of a wind characteristic at each site, whereby this data may be interpreted to identify for example the optimum location of a wind farm, or to investigate for example the effective turbulence zone around a wind turbine.

According to another aspect of the present invention there is provided a system for monitoring wind characteristics over an area of land, said system comprising:

a plurality of portable wind characteristic measuring means, each of which is adapted to output a data signal which is indicative of the value of at least one wind characteristic;

a data signal receiving unit;

communication means for carrying the data signal from each wind characteristic measuring means to said data signal receiving unit;

processing means for creating data from said received signal, said data representing said wind characteristic over said area of land.

Advantageously, the system further comprises a display means such as a visual display unit which

may provide a real time representation of the value of a wind characteristic over said area.

In a preferred embodiment, data from the area is logged over a period of time on a recording means, and that recorded data may be subsequently analysed. The recorded data may be downloaded to another recording means so that it can wnloaded to to a different location for analysis or alternatively the recording means itself may be transported to a different location for analysis.

Preferably, the wind characteristic measuring means comprises a balloon or kite-like device which is tethered to an anchor point on the ground, the position of that device relative to the anchor point being measured and various wind characteristics being inferred from that measurement.

Preferably, the relative position of the balloon or kite-like device from the anchor point measured by a differential GPS system.

Preferably the wind characterisic measursing means is supported on a support means which is extendable such that it can be deployed at different elevations. In a preferred embodiment using a balloon or kite-like device the length of the means tethering the balloon or kite-like device to the anchor point is adjustable.

The invention will allow for much denser and more regular ground coverage than is normal, and much more frequent time sampling. Preferably the invention

will allow the deployment of large numbers of simple and low cost detectors. This deployment can be at any elevation above ground, dependent on the scope of the survey objectives.

The electrical output of the detectors may be calibrated by the use of more sophisticated and accurate devices placed at strategic locations within the survey area. This calibration may be performed by Fourier analysis and decomposition of the time series signals produced by the simple detectors with respect to the calibration signals. This calibration can take place any time after the signals are recorded.

The invention may also provide a real-time (less than a few milliseconds delay) three dimensional display of the response of the detectors. For example, the data may be processed to provide a screen image on a colour computer monitor, such that the horizontal axis represents the easting coordinate of the detector locations, the vertical axis represents the northing coordinate of the detector locations, and individual screen pixels are coloured according to the values output by the deployed detectors.

As a further example, the wind speed and direction may be displayed on the screen as arrows or vectors. The blunt end of the arrows are positioned at a fixed location on the screen, corresponding to the coordinates of the detectors, the length of the arrows representing the magnitude of the wind speed and the direction of the arrows representing the azimuth of the wind.

The invention will now be described further with reference to and as illustrated in the accompanying drawings in which:

Figure 1 is a schematic diagram of a first embodiment of the present invention as deployed over a chosen survey area with detection devices, recording media, data processing and display means; and

Figure 2 is a schematic view of a wind characteristic measuring means according to a second embodiment of the present invention;

Figure 3 is a schematic view of the second embodiment of the present invention being deployed around a wind turbine;

Figure 4 is a simulation of a possible display of the data obtained by the apparatus of the first or second embodiment of the present invention.

Referring to the drawings, Figure 1 shows an array of detectors 1 deployed in a spatially regular manner over an area of land. The detectors 1 are supported and held in a generally vertical position by support means 2. The height of the detectors 1 above the ground can be adjusted by adjusting the height of the support means 2. The electrical output from the detectors is transmitted via telemetry or wires 3 to local line control units 4. These line control units incorporate internal data storage means in addition to process control means and are connected via telemetry or wires to a central recording and control unit (RCU) 5. The RCU 5 has data links to various recording

means 6 and an additional computer 7. Attached to the computer 7 are further recording means 8, computer screen video display unit 9, keyboard and mouse 10 and paper printing means 11. Line control units 4 and the recording and control unit 5 may have means to multiplex and demultiplex the electrical signals from analogue to digital format and from digital format to analogue. Similarly the computer 7 may also have means to multiplex and demultiplex from analogue to digital format and vice versa. In addition the computer 7 will possess means to record data onto various storage means 8, reproduce data from recording media 8, process data using computer programs and record the results on storage means 8 or display the results on the video screen 9 or reproduction means 11.

The components numbered 1 through 6 may be capable of operating in isolation from the components 7 through 11. This allows the computer to be used for the processing of previously recorded data or the real-time monitoring of current data recording.

The processing equipment receives data from the detectors 1 and processes this data to enable an operator to identify an optimum position or positions for a wind farm.

An alternative wind characteristic measuring means is shown in Figure 2. As shown in that figure, anchor modules 51, are deployed regularly over an area of land. Attached to the anchor modules are umbilical tethering devices of variable and controllable length 52, consisting of a shielded electrical conductor 53,

and a tube 54, capable of transporting some lighter than air gas to a balloon 55.

Supported by the balloon 55, is an antenna 56, electrically connected to the conductor 53. The antenna 56 is specifically dimensioned so as to act as the antenna of a rover component of a differential Global Positioning System (GPS). The electronics associated with the rover are housed in the anchor 51.

Associated with the array of rover devices will be one or more base stations 57, at known geographical positions as in Figure 3. Both the base stations and the rovers will receive radio transmissions from satellites orbiting the Earth. This is conventional GPS methodology.

When deploying the system, the positions of the anchors 51 are determined precisely and this information is made available to computer programs. Also, for each anchor 51, the length of deployed umbilical 52 is also known precisely and is also made available to the same same computer programs. Thus by knowing the horizontal/vertical deviation of the balloon and the wind speed vs. deviation characteristics for a specific device geometry than instantaneous wind speeds and other turbulence characteristics can be inferred.

The differential GPS system may operate in one of two modes, either REAL-TIME or RECORDING ONLY.

In the real-time mode, precise position data from each rover will be relayed to the base station so that data can be electronically displayed and/or recorded for future analysis.

In the recording-only mode, raw satellite data received at the rovers is transmitted to the base station for recording and future analysis.

The base station and rovers incorporate an electronic multiplexing system, such that each rover is interrogated at fixed time intervals.

The maximum value of the sample time interval is determined by the minimum turbulence wavelength to be detected. For example, commercial wind turbine equipment has a diameter of 10's of meters, and is unlikely to be affected by turbulence wavelengths of less than a few meters.

If v is the wind speed at which measurements are to be made and L is the minimum desired turbulence wavelength to be measured, then the minimum sample time interval for each rover station is given by:

$$T = L/4v$$

The minimum measurable turbulence wavelength is also determined by the physical dimensions of the balloon. For example, a balloon of diameter one meter is unlikely to be affected by turbulence cells of 10cm wavelength or

less and a wind turbine of 40 meter diameter is unlikely to be affected by a turbulence wavelength of 1 meter.

For example, given the extreme requirements of L=2m and a v=20m/s, then all rover stations must be sampled within a time of 25 milliseconds. This is termed the "Half Nyquist" smaple interval and represents the largest sampling interval permitted to completely define the wavelength in question.

It will be seen that the second embodiment may allow the turbulence around a piece of wind plant to be investigated.

CLAIMS:

1. A method of monitoring wind characteristics over an area of land, comprising the steps of: locating a wind characteristic measuring means at each of a number of sites, so that said wind characteristic measuring means are arranged into a spatial array over said area; each wind characteristic measuring means being adapted to output a data signal which is indicative of the value of one or more wind characteristics, passing said data signals from each wind characteristic measuring means to a data receiving means; and processing the received data signals to provide data representing the value of a wind characteristic at each site, whereby this data may be interpreted to identify for example the optimum location of a wind farm, or to investigate for example the effective turbulence zone around a wind turbine.

2. A method according to claim 1 wherein said processing step includes the step of providing a real time display of said wind characteristic over said area.

3. A method according to claim 1 wherein said processing step comprises the step of recording said data for later analysis .

4. A system for monitoring wind characteristics over an area of land, said system comprising:

a plurality of portable wind characteristic measuring means, each of which is adapted to output a data signal which is indicative of the value of at least one wind characteristic;

a data signal receiving unit;

communication means for carrying the data signal from each wind characteristic measuring means to said data signal receiving unit;

processing means for creating data from said received signal, said data representing said wind characteristic over said area of land.

5. A system according to claim 4 further comprising a display means for displaying said data representing said wind characteristic over said area of land.

6. A system according to claim 4 wherein said processing means comprises a recording means for recording said data representing said wind characteristic over said area of land.

7. A system according to claim 4 wherein said wind characteristic measuring means comprises:

a wind responsive means adaptable to become airborne;

a tethering means for tethering said wind responsive means;

an anchoring means for connecting to said tethering means;

the arrangement being such that the position of said wind responsive means relative to said anchoring means may be measured and one or more of said wind characteristics may be inferred from that measurement.

8. A system according to claim 7 wherein a length of said tethering means is adjustable.

9. A system according to claim 7 wherein said wind responsive means is provided by a gas filled balloon.

10. A system according to claim 7 wherein said responsive means supports an antenna for receiving position indicating electromagnetic signals.

11. A system according to claim 10 wherein said electromagnetic signals are received from a global positioning system.

12. A system according to claim 10 wherein said tethering means comprises a conductor;

whereby signals received by said antenna are transmitted via said conductor to said connecting means.

13. A method of monitoring wind characteristics substantially as hereinbefore described.

14. A system for monitoring wind characteristics substantially as herein before described as a reference to and as illustrated in Figure 1.

15. A system for monitoring wind characteristics substantially as hereinbefore described with reference to and as illustrated in Figures 2 and 3.

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report) - 15 -

Application number
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Relevant Technical Fields

(i) UK Cl (Ed.M) G1N (NAAA, NAAK, NAHJA, NAHJD)

(ii) Int Cl (Ed.5) G01P 5/00, 13/00

Search Examiner
M G CLARKE

Date of completion of Search
28 SEPTEMBER 1994

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE DATABASES: WPI, INSPEC

Documents considered relevant following a search in respect of Claims :-
1 TO 15

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
X, Y	WO 92/22882 A1 (UNIV. CORPN. FOR ATMOSPHERIC RESEARCH) - whole document	1, 4 at least
X, Y	US 5221924 (ass. to UNIV. CORPN FOR ATMOSPHERIC RESEARCH) whole document	1, 4 at least
Y	US 4155252 (R A MORRILL) whole document	1, 4 at least
A	G J Taylor, "Full Scale Measurements in Wind Turbine Arrays"; European Community Wind Energy Conference, proceedings pub. 1990, H S Stephens, Bedford pages 154-158, see especially page 156	
X	Boundary-Layer Meteorology, Vol 19, No 2, September 1980, Netherlands, H W Teunissen, "Structure of Mean Winds and Turbulence in the Planetary Boundary over Rural Terrain" pages 187-221, see especially pages 193-4	1 at least

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).